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Functional understanding facilitates learning about tools in human children

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Human children benefit from a possibly unique set of adaptations facilitating the acquisition of knowledge about material culture. They represent artifacts (human-made objects) as tools with specific functions and seek for functional information about novel objects. Even young infants pay attention to functionally relevant features of objects, and learn tool use and infer tool functions from others' goal-directed actions and demonstrations. Children tend to imitate causally irrelevant elements of tool use demonstrations, which helps them to acquire means actions even before they fully understand their causal role in bringing about the desired goal. Although non-human animals use and make tools, and recognize causally relevant features of objects in a given task, they – unlike human children – do not appear to form enduring functional representations of tools as being *for* achieving particular goals when they are not in use.

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Introduction

Even though neither tool manufacture nor tool use is a uniquely human capacity, humans create and transform their environment to a degree unparalleled in other animal species. The environment of modern people is predominantly human-made, and almost all kinds of everyday activities, from walking and playing, through food preparation and eating, to communicating and socializing, involve artifacts as tools for achieving desired outcomes. Recent research on human children suggests that acquiring knowledge of human material culture is made possible by cognitive systems that facilitate learning about artifacts by representing them in terms of their function.

Humans tend to conceptualize tools in terms of their *function*, that is, the outcome that a given kind of artifact, owing to its designed physical structure, helps to bring about when used in goal-directed actions. This functional conception of tools is not tied to actions: people tend to think that an artifact is *for* something (has a function), even when it is currently not in use. Young children also expect that artifacts have functions, which is evident in the questions they ask when confronted with novel one [1–3]. For example, young preschoolers who are only told the name of the novel tool keep asking for more information about it than those who are told its function [1].

By contrast, there is no evidence that non-human animals, even the ones who are proficient toolmakers and tool users, would think about an object in terms of its potential function when they are not in need to fulfill that function. For example, preparing, pre-manufacturing, and storing tools are rare in non-human animals, even though they seem to be able think about the future ([4] but see [5]). The only experimental evidence of storing tools for later use by apes involved planning for the future in the context of cues that reminded them of the goal to be achieved the next day [6•] (see also [7]). It seems that many species are capable of reasoning about potential means to achieve a certain desirable goal (NJ Emery and NC Clayton, this issue), but would not be engaged in thinking about potential goals (i.e. functions) when they are confronted with an object (Table 1). This is exactly the challenge human children are faced with when they enter the world full of culturally defined artifacts.

Understanding a tool in terms of its function requires: (i) understanding the causal relations between the artifact's physical features and the outcomes of its use (sometimes dubbed its causal *affordances*), which, in case of many artifacts, remain cognitively opaque; (ii) the ability to identify and master the tool's usage, while any artifact can be operated in countless ways, and observable actions typically involve many elements irrelevant for bringing about the outcome; and (iii) the ability to identify specific goals of tool-using actions, while every action and every tool causally contributes to bringing about countless outcomes (some of them distant in time). Recent advances in developmental research, reviewed here, show that human children are dealing with this challenge remarkably well. They acquire artifact functions by considering various sources of information in figuring out what a tool is *for*: they reason what it is *good for*, they observe what it is *used for*, and they seek to find out what it is *made for*.

Table 1

Comparison of phenomena reflecting the cognitive bases of tool understanding in human children and in non-human animals.

	Human children	Non-human animals
Attention to causally relevant tool properties	Yes	Yes
Inferring means from goals and matching tools to desired outcomes	Yes	Yes
Inferring goals from observed means actions and finding functions for objects	Yes	No
Forming enduring functional representations of tools	Yes	No
Overimitation of causally irrelevant means actions involving tools	Yes	No
Acquiring tool use and tool functions through communication	Yes	No

Attending to functionally relevant features

An artifact's function could be guessed from its physical features (shape, sharpness, hardness, etc.). Such physical evaluation assesses what a certain object is *good for*, relying on the implicit assumption that tools approximate the optimal design for their function. It has been argued that infants apply a similar assumption toward observed actions [8] and can predict their goals accordingly [9,10].

Many studies document the importance of a tool's overall appearance, in particular, its shape, for early word learning and categorization in human infants [11•,12,13••]. Some studies have suggested that infants may differentiate between broad domains that include tokens of various shapes (like vehicles), and associate actions (like giving a ride) typical to objects belonging to these domains (for reviews see [14,15]). However, evidence for more fine-grained early appreciation of functional features and their role in function-based categories was rather scarce [16].

New research suggests that infants pay attention to an artifact's physical features that causally contribute to the achievement of a goal. For instance, when crossing a narrow bridge fitted with either elastic or rigid handrails, 16-month-olds take elasticity of the handrails into account and change their behavior accordingly [17]. Attention to an artifact's functionally relevant features may be in place even earlier. In a study by Träuble and Pauen [13••], 11- to 12-month-olds witnessed a series of short demonstrations, in which various novel artifacts with a common functional feature (a T-shaped projection) were used to bring about the same outcome (e.g. pulling a pair of hooks out of the apparatus). Later, when given opportunity to explore a new pair of objects, they tended to explore longer the objects with novel rather than familiar orientation of the crucial T-shaped part. The effect was not present in a group who watched matched demonstrations that did not involve achieving any goal.

In older children, attention to the causal relations between the tool's physical features and the goal it helps to bring about may even override the tendency to imitate adults [18]. Four-year-olds chose to perform the modeled action (e.g. crushing cookies) with the tool of optimal physical features even when a less functional tool (e.g. cotton pom-poms), used by the adult demonstrator, was introduced as designed for the task, or if its affordance for the task was only suboptimal. Moreover, as already suggested by the results of the Träuble and Pauen's [13••] study, attention to an artifact's physical features in relation to its function is not restricted to the choice of tool for the current action. If the function presented by an adult leaves salient features unexplained, young preschoolers are less likely to extend the artifact's name on the basis function rather than appearance [19], and tend to ask function-related follow-up questions [3]. When presented with transformed non-functional versions of familiar artifacts (e.g. a modified cup), children tend to extend the category name to the exemplars with physical features suggesting accidental (e.g. a piece broken out) rather than intentional (e.g. a hole rimmed with metal) transformation [20].

Attentiveness to functional properties of tools is the most studied cognitive aspect of tool use in non-human animals. Intriguingly, cotton-top tamarins, which have been shown to discriminate between functionally relevant (e.g. shape, material, location in relation to the target object) vs. irrelevant (e.g. color) properties when choosing tools in problem-solving tasks, are not tool users in the wild (see [21] for a review and forthcoming results from other primate species). On the contrary, New Caledonian crows, which are, by avian standards, prolific tool users [22] and tool manufacturers [23], failed in similar tasks [24]. This evidence strongly suggests that understanding of the physical causal relations between tool structure and the potential outcome of goal-directed tool use is not sufficient for representing tools as objects implementing a specific function.

Learning tool use from others

The causal structure of many tools (e.g. a remote control) surrounding us in everyday life is not transparent enough to play a role in our representations of these artifacts. Even less so for children, who nevertheless develop an understanding of tools and their functions. In the absence of veridical causal knowledge of novel tools that could constrain social learning of observable means actions, human children display a tendency to *overimitate* modeled actions [25••,26,27], that is, their acquired use of the artifact tends to include elements of the modeled action sequence that are not causally relevant for achieving the goal (see also [28]). This tendency can also be demonstrated even when children are warned to be vigilant against causally irrelevant elements of the modeled action sequence [25••]. On the contrary, no overimitation was found when the modeled irrelevant action was at odds with fundamental causal assumptions, for example, when it would have implied causation at a distance [25••,26]. Toddlers are also less likely to imitate faithfully if the modeled use brings about the outcome not every but only half of the times [29]. Taken together, this evidence suggests that overimitation is mediated by the assumption that all elements in an observed action sequence might play a causal (even if opaque) role in fulfilling the artifact's function.

Chimpanzees (among other species, [30]) acquire means actions from their conspecifics by social learning [31], and they may even copy physically irrelevant elements of a means action if the causal structure of the artifact is not accessible to them. However, once the causal structure of the artifact is clear, they – unlike children – show no signs of overimitation [27].

In human children, overimitation of irrelevant actions is facilitated when the modeled means action is presented within a communicative context [26,32,33]. These results are consistent with the recent theoretical proposal of 'Natural Pedagogy' [34•]—a uniquely human adaptation for transmission of cultural knowledge (including tool use and tool function) by communication.

Enduring functional representations

A characteristic feature of human functional representations of tools is their endurance: artifacts are understood as being *for* achieving particular goals, and these function-object mappings do not readily change from task to task even though every tool, in virtue of its physical features, affords achieving various goals [35]. Some recent results suggest that the formation of enduring functional representations of novel tools starts in early toddlerhood [36••]. After witnessing a successful goal-directed action involving a novel tool, when asked two to four days later to bring about the same goal, 24-month-olds tended to choose the familiar tool over another, equally suitable tool for the task. However, they also preferred to use it to accomplish other tasks, which suggests that they did not yet treat the modeled function as exclusive to this artifact.

Exclusive function-object mappings start to emerge in the third year of life [37], leading to a phenomenon known as functional fixedness [35] in problem solving tasks a couple of years later. Preschoolers sometimes display the primacy effect, a tendency to rely more on the first function learnt about an object than on later ones ([38], M Hernik and M Haman, unpublished). This suggests that children tend to form a lasting functional representation of an artifact as soon as they acquire its function.

When judging what the artifact is for, or when deciding its appropriate label, human adults and older preschoolers tend to rely on the artifact's history (i.e. what it was designed and *made for*) [39] (for a review see [40]). Whether the same is true for children younger than six years of age is currently a matter of controversy with some studies demonstrating that younger children prefer only the label but not the function intended by the artifact's creator [41], and some suggesting that children's function judgments may be mediated by their beliefs about conventional use [42].

Conclusions

Recent advances in research on tool understanding in human children and non-human animals point to possible differences in cognitive mechanisms underlying tool use in humans and other species. While non-human animals understand means and ends, they do not search for goals for any action, and do not search for functions for any object they are confronted with. By contrast, humans are obsessed with goals [43] and functions [44] from early on, giving them a teleological bias in interpreting both the social and the material world. Further comparative, developmental, and neuroimaging studies are needed to pinpoint the exact neuro-cognitive bases of these differences. These studies should also assess whether some of the cross-species differences in the understanding of tools reviewed here (Table 1) might be exaggerated owing to limitations of the methods employed to study them. One such limitation, often discussed in the literature [45,46], may come from the fact that non-human apes are often expected to learn about tools from human demonstrators rather than from conspecifics, and hence may be handicapped in expressing their cognitive grasp of tools. Even though little evidence supports this hypothesis directly [47], it should be taken into account when judging the ecological validity of future tasks focusing on cognitive bases of tool use. Secondly, once ctitical ages for acquiring tool use are identified in a species [48], they should be taken into account when choosing age groups for comparisons with human children. Finally, since enculturated apes (i.e. individuals reared by humans and exposed to human culture) outperform mother-reared apes in imitation tasks involving novel objects [49], further studies with such groups are crucial to test the extent that the differences in functional representation of tools, which we attribute to differences in cognitive mechanisms, can be modulated, or perhaps even explained, by the amount of exposure to a rich material culture. From a different angle, this question can also be addressed in cross-cultural studies with human subjects [50].

Meanwhile, it is important not to lose track of the phenomena that characterize early human learning about artifacts (Table 1). Human children, who, in contrast to other species, develop in extensive, complex, and cognitively opaque material cultures, are remarkably good students. They can reason about the potential goals of actions they witness from early on [51,52]. They quickly learn the use and function of tools from others' demonstrations [25••,13••], and they form enduring function-object mappings [36••]. They tend to treat artifacts as being *for* a specific function [37,35], and subsequently start to appreciate the importance of an artifact's design (i.e. the creator's intention) in determining this function [40], as well as become aware of conventions governing artifact's use [42]. Children benefit from a possibly unique set of adaptations for acquiring human material culture, as can be seen (i) in their over-attribution of causal roles to irrelevant elements of demonstrated tool use in the absence of veridical causal knowledge of most novel artifacts; (ii) in their expectation that artifacts have functions and in their seeking for functional information about them; and (iii) in the acquisition of novel artifact functions by inference from observed goal-directed tool use and through learning from others by communication.

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References and recommended reading

Papers of particular interest published within the period of review have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Kemler Nelson DG, Egan LC, Holt MB: **When children ask, 'what is it?' What do they want to know about artifacts?**. *Psychol Sci* 2004, **15**:384-389.

2. Greif ML, Kemler Nelson DG, Keil FC, Gutierrez F: **What do children want to know about animals and artifacts? Domain-specific requests for information**. *Psychol Sci* 2006, **17**:455-459.

3. Asher YM, Kemler Nelson DG: **Was it designed to do that? Children's focus on intended function in their conceptualization of artifacts**. *Cognition* 2008, **106**:474-483.

4. Raby CR, Alexis DM, Dickinson A, Clayton NS: **Planning for future by Western Scrub-Jays**. *Nature* 2007, **445**:919-921.

5. Suddendorf T, Corballis MC: **Mental time travel across the disciplines: the future looks bright**. *Behav Brain Sci* 2007, **30**:335-351.

6. • Mulcahy NJ, Call J: **Apes save tools for future use**. *Science* 2006, **312**:1038-1040.

A unique study providing the only experimental evidence of storing tools for later use in apes. The task required planning for the future in the context of cues that reminded the apes of the goal to be achieved the next day.

7. Suddendorf T: **Foresight and evolution of the human mind**. *Science* 2006, **312**:1006-1007.

8. Gergely G, Csibra G: **Teleological reasoning in infancy: the naive theory of rational action**. *Trends Cogn Sci* 2003, **7**:287-292.

9. Csibra G, Bíró S, Koós O, Gergely G: **One-year-old infants use teleological representations of actions productively**. *Cogn Sci* 2003, **27**:111-133.

10. Wagner L, Carey S: **12-month-old infants represent probable endings of motion events**. *Infancy* 2005, **7**:73-83.

11. • Samuelson LK, Bloom P (Eds): *Dev Sci*, 11 *Special section: what counts as an explanation of development: the shape bias as a case study*. 2008, **11**:183-222.

An informative discussion of recent advances in research on the so-called 'shape bias' in early naming and categorization of artifacts.

12. Booth AE: **Object function and categorization in infancy: two mechanisms of facilitation**. *Infancy* 2006, **10**:145-169.

13. •• Träuble B, Pauen S: **The role of functional information for infant categorization**. *Cognition* 2007, **105**:362-379.

Object-examination times show that 11-month-old to 12-month-old infants categorize novel objects according to their functionally relevant parts if, and only if, they witnessed a demonstration of this part's role in bringing about an outcome in a goal-directed action.

14. Mandler JM: **The conceptual foundations of animals and artifacts**. In *Creations of the Mind. Theories of Artifacts and Their Representations.* Edited by Margolis E, Laurence S. Oxford University Press; 2007:191-211.

15. Mandler JM: *The Foundations of Mind: Origins of Conceptual Thought*Oxford University Press; 2004.

16. Kemler Nelson DG, Russell R, Duke N, Jones K: **Two-year-olds will name artifacts by their functions**. *Child Dev* 2000, **71**:1271-1288.

17. Berger SA, Adolph KE, Lobo SA: **Out of the toolbox: toddlers differentiate wobbly and wooden handrails**. *Child Dev* 2005, **76**:1294-1307.

18. DiYanni C, Kelemen D: **Using a bad tool with good intention: young children's imitation of adults' questionable choices**. *J Exp Child Psychol* 2008, **101**:241-261.

19. Kemler Nelson DG, Frankenfield A, Morris C, Blair E: **Young children's use of functional information to categorize artifacts: three factors that matter**. *Cognition* 2000, **77**:133-168.

20. Kemler Nelson DG, Holt MB, Chan Egan L: **Two- and three-year-olds infer and reason about design intentions in order to categorize broken objects**. *Dev Sci* 2004, **7**:543-549.

21. Hauser MD, Santos LR: **The evolutionary ancestry of our knowledge of tools: from percepts to concepts.** In *Creations of the Mind. Theories of Artifacts and Their Representations.* Edited by Margolis E, Laurence S. Oxford University Press; 2007267-288.

22. Taylor AH, Hunt GR, Holzhaider JC, Gray RD: **Spontaneous metatool use in New Caledonian Crows**. *Curr Biol* 2007, **17**:1504-1507.

23. Kenward B, Weir AAS, Rutz C, Kacelnik A: **Tool manufacture by naive juvenile crows**. *Nature* 2005, **433**:121.

24. Holzhaider JC, Hunt GR, Campbell VM, Gray RD: **Do wild New Caledonian crows (*Corvus moneduloides*) attend to the functional properties of their tools?** *Anim Cogn* 2008, **11**:243-254.

25. •• Lyons DE, Young AG, Keil FC: **The hidden structure of overimitation**. *Proc Natl Acad Sci U S A* 2007, **104**:19751-19756.

Children tend to overimitate modeled actions involving novel tools: they reproduce elements of actions that do not contribute causally to achieving the outcome. Results are discussed in the context of children's developing causal understanding of cognitively opaque artifacts.

26. Brugger A, Lariviere LA, Mumme DL, Bushnell EW: **Doing the right thing: infants' selection of actions to imitate from observed event sequences**. *Child Dev* 2007, **78**:806-824.

27. Horner V, Whiten A: **Causal knowledge and imitation/emulation switching in chimpanzees (*Pan troglodytes*) and children (*Homo sapiens*)**. *Anim Cogn* 2005, **8**:164-181.

28. Gergely G, Csibra G: **Sylvia's recipe: the role of imitation and pedagogy in the transmission of human culture**. In *Roots of Human Sociality: Culture, Cognition, and Human Interaction.* Edited by Enfield NJ, Levinson SC. Berg Publishers; 2006229-255.

29. Schulz LE, Hooppell K, Jenkins A: **Judicious imitation: young children imitate deterministic actions exactly, stochastic actions more variably**. *Child Dev* 2008, **79**:395-410.

30. Whiten A, van Schaik CP: **The evolution of animal 'cultures' and social intelligence**. *Philos Trans R Soc Lond B Biol Sci* 2007, **362**:603-620.

31. Whiten A, Spiteri A, Horner V, Bonnie KE, Lambeth SP, Schapiro SJ, de Waal FBM: **Transmission of multiple traditions within and between chimpanzee groups**. *Curr Biol* 2007, **17**:1038-1043.

32. Nielsen M: **Copying actions and copying outcomes: social learning through the second year**. *Dev Psychol* 2006, **42**:555-565.

33. Gergely G, Bekkering H, Király I: **Rational imitation in preverbal infants**. *Nature* 2002, **415**:755.

34. Csibra G, Gergely G: **Natural pedagogy**. *Trends Cogn Sci* 2009,
• **13**:148-153.
A theoretical paper outlining the Natural Pedagogy hypothesis, according to which human cognition is adapted to the need of transmission of cultural knowledge, including artifact function and use, via communication.

35. Defeyter MA, German TP: **Acquiring an understanding of design: evidence from children's insight problem solving**. *Cognition* 2003, **89**:133-155.

36. Casler K, Kelemen D: **Reasoning about artifacts at 24 months:**
•• **the developing teleo-functional stance**. *Cognition* 2007, **103**:120-130.
After a brief presentation of how to achieve a particular goal with a novel artifact, 24-month-olds return to this artifact when asked to achieve the same goal two to four days later, and they prefer it over another functionally equivalent object. However, they tend to overgeneralize the use of the demonstrated artifact.

37. Casler K, Kelemen D: **Young children's rapid learning about artifacts**. *Dev Sci* 2005, **8**:472-480.

38. Matan A, Carey S: **Developmental changes within the core of artifact concepts**. *Cognition* 2001, **78**:1-26.

39. Chaigneau S, Castillo R, Martinez L: **Creators' intentions bias judgments of function independently from causal inferences**. *Cognition* 2008, **109**:123-132.

40. Kelmen D, Carey S: **The essence of artifacts: developing the design stance**. In *Creations of the Mind. Theories of Artifacts and Their Representations.* Edited by Margolis E, Laurence S. Oxford University Press; 2007:212-230.

41. German TP, Truxaw D, Defeyter MA: **The role of information about 'Convention', 'Design', and 'Goal' in representing artifact kind**. *New Dir Child Adolesc Dev* 2007, **115**:69-81.

42. Siegel DR, Callanan MA: **Artifacts as conventional objects**. *J Cogn Dev* 2007, **8**:183-203.

43. Csibra G, Gergely G: **'Obsessed with goals': functions and mechanisms of teleological interpretation of actions in humans**. *Acta Psychol* 2007, **124**:60-78.

44. Kelemen D: **Function, goals, and intention: children's teleological reasoning about objects**. *Trends Cogn Sci* 1999, **3**:461-468.

45. de Waal FBM, Boesch C, Horner V, Whiten A: **Comparing social skills of children and apes**. *Science* 2008, **319**:569.

46. Boesch C: **What makes us human (*Homo sapiens*)? the challenge of cognitive cross-species comparison**. *J Comp Psychol* 2007, **121**:227-240.

47. Herrmann E, Call J, Hare B, Hernandez-Lloreda M, Tomasello M: **Response to de Waal, Boesch, Horner & Whiten 2008**. *Science* 2008, **319**:570.

48. Marshall-Pescini S, Whiten A: **Social learning of nut-cracking behaviour in East African sanctuary-living chimpanzees**. *J Comp Psychol* 2008, **122**:186-194.

49. Tomasello M, Savage-Rumbaugh S, Kruger A: **Imitation of object-related actions by chimpanzees and human infants**. *Child Dev* 1993, **64**:1688-1705.

50. German T, Barrett HC: **Functional fixedness in a technologically sparse culture**. *Psychol Sci* 2005, **10**:1-5.

51. Csibra G: **Goal attribution to inanimate agents by 6.5-month-old infants**. *Cognition* 2008, **107**:705-717.

52. Sommerville JA, Woodward AL, Needham A: **Action experience alters 3-month-old infants' perception of others' actions**. *Cognition* 2005, **96**:B1-B11.